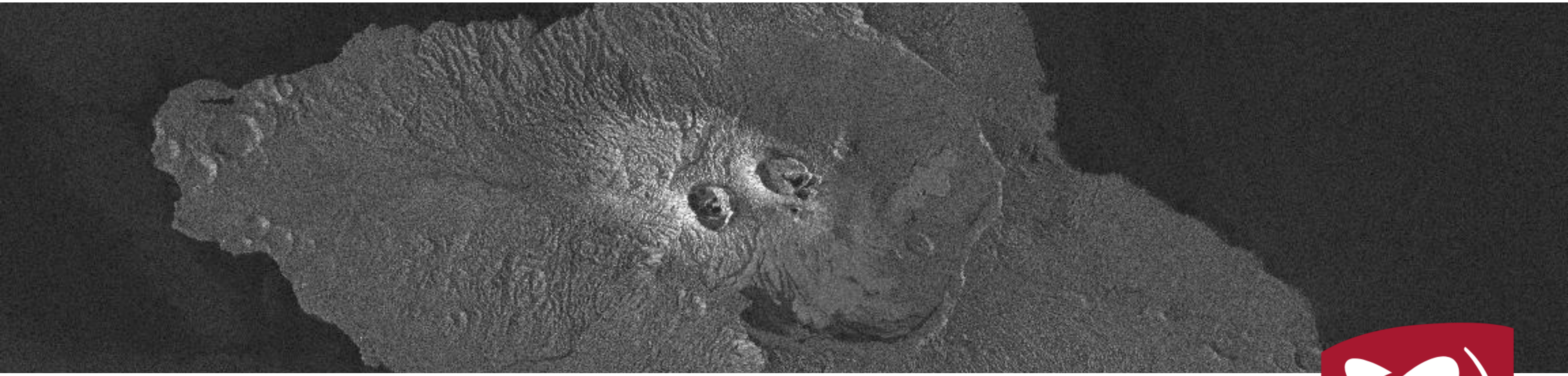
Are chilled basaltic magmas more susceptible to earthquake triggering? Evidence from the 2015 Ambrym, Vanuatu, dyke intrusion



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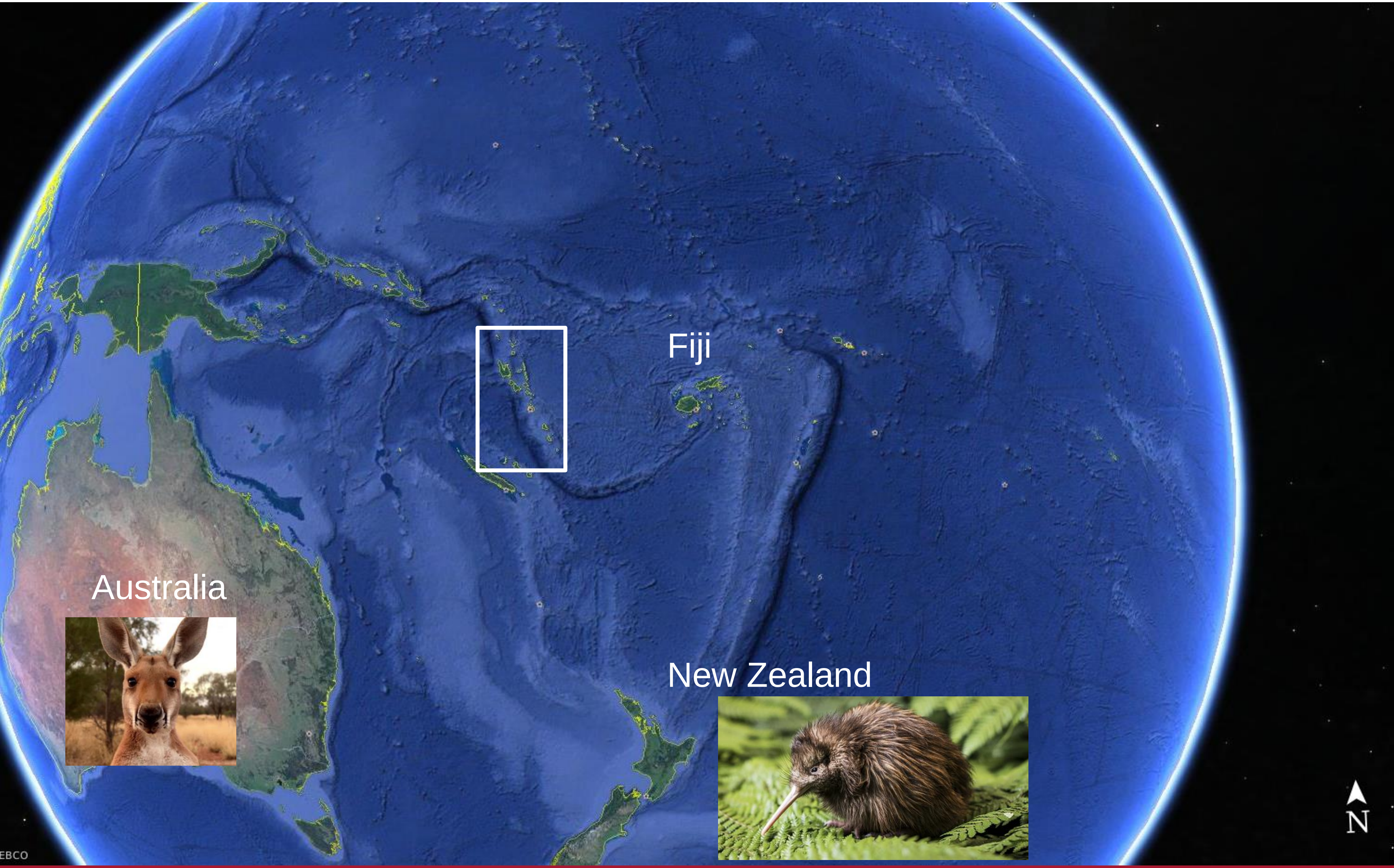
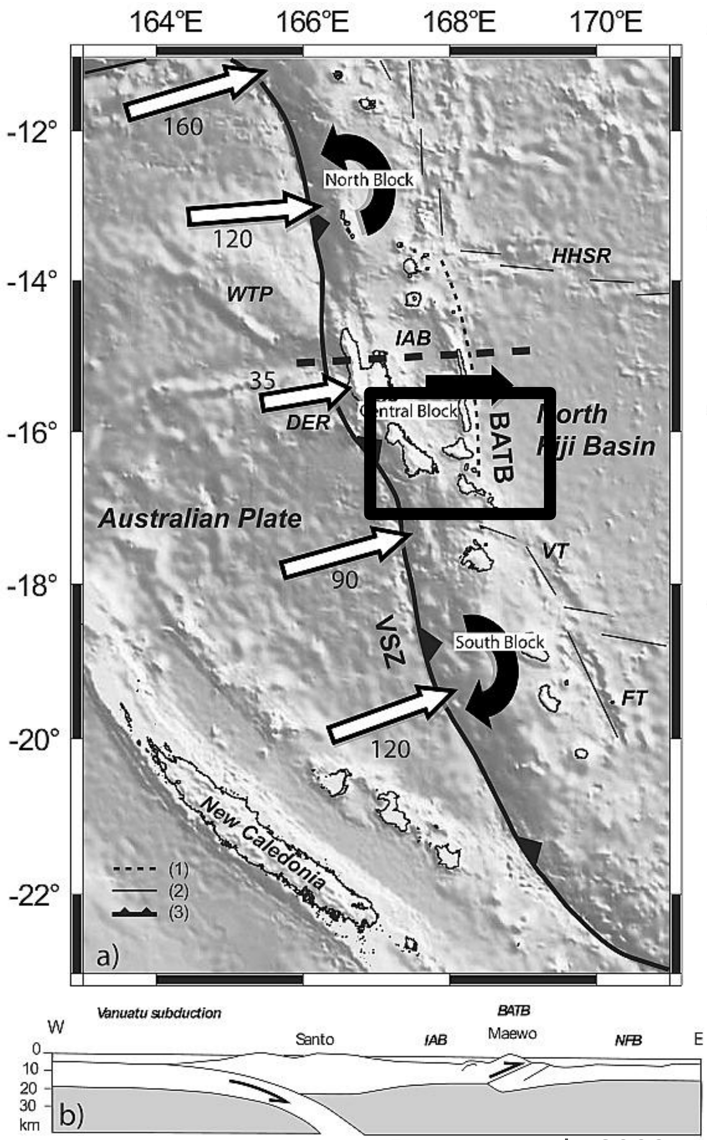
2. GNS Science, Wairakei


Yes, I think!

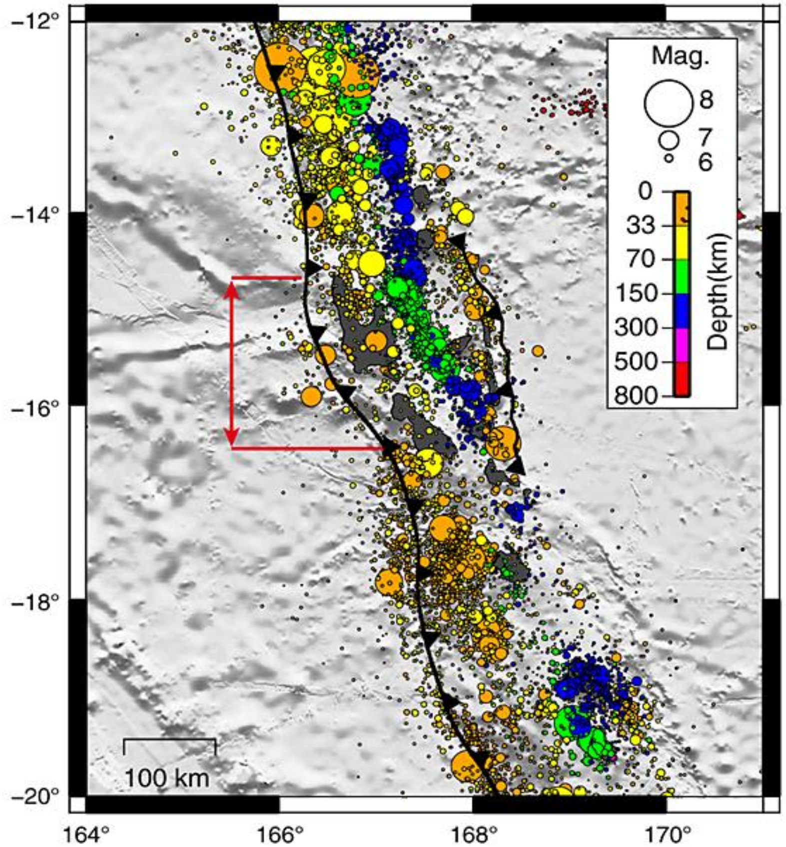
Tectonic Setting



Tectonic Setting



Bergeot et al., 2009



Baillard et al 2015

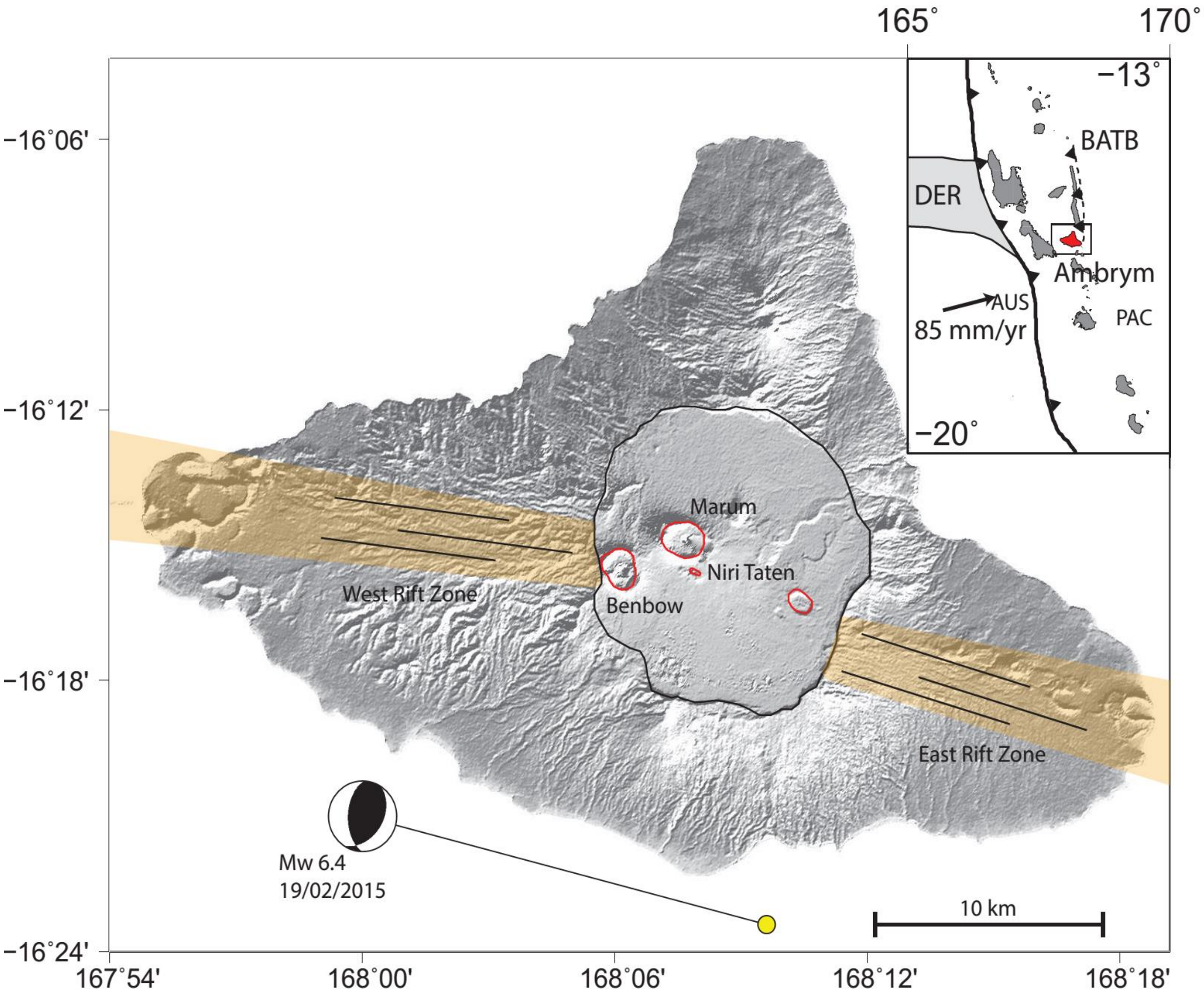
Tectonics are dominated by the subduction of the Australian plate beneath Pacific plate.

Strong along strike variation in convergence rate with seismic gap

Volcanism is associated with back-arc extension.

However, in central Vanuatu the subduction of the D'Entrecasteaux ridge has led to compression.

Tectonic Setting

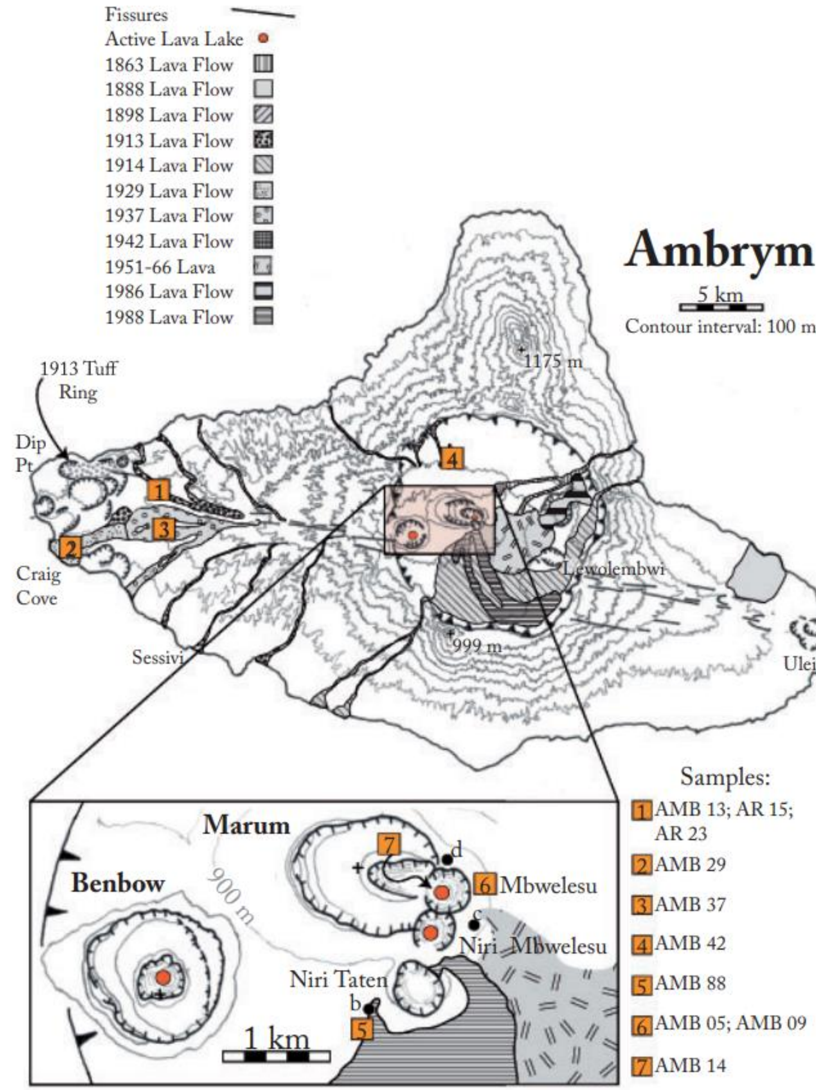


The island contains a large 12 km wide caldera which sits above ESE trending rift zones.

Earliest recorded activity was in 1774 by Captain Cook

Since then there have been multiple flank eruptions

Tectonic Setting



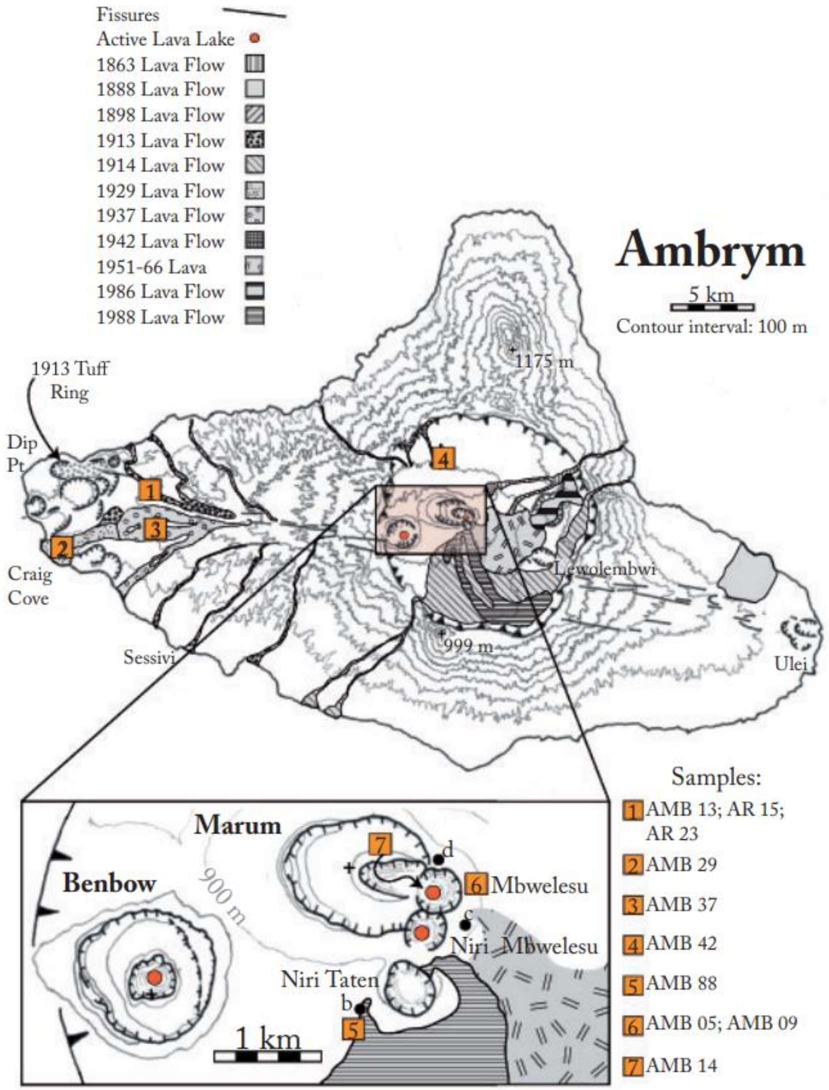
Firth et al., 2016

Current volcanism is focussed at Benbow and Marum cones.

The Marum cone hosts two active vents, and a third vent, Niri Taten, opened on its outer flanks during the 1988 eruption.

All three vents are deep (>200 m), steep sided and commonly host active lava lakes

Tectonic Setting

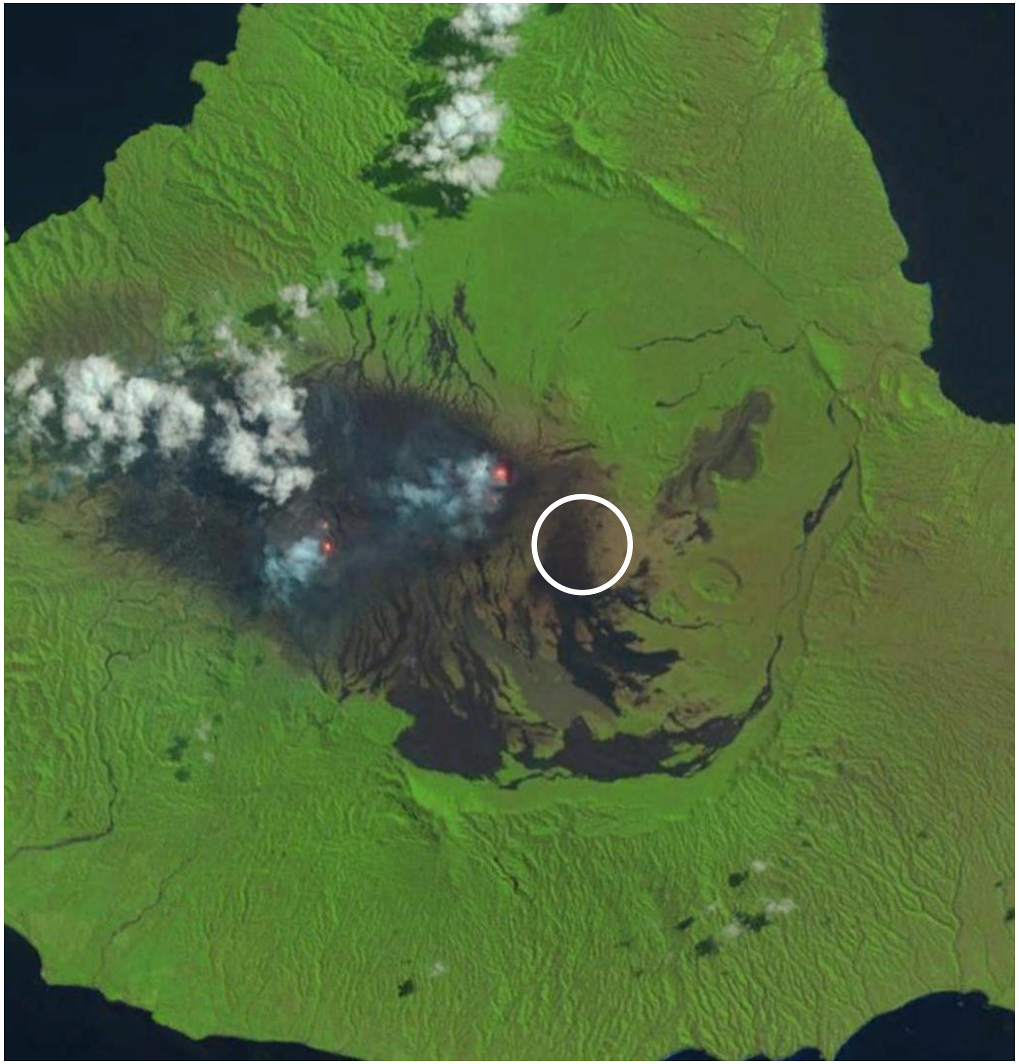


Both Benbow and Marum are thought to share a common source at depth.

Based on seismicity and gas flux data, the main reservoir is thought to be located at 3-4 km depth.

Firth et al., 2016

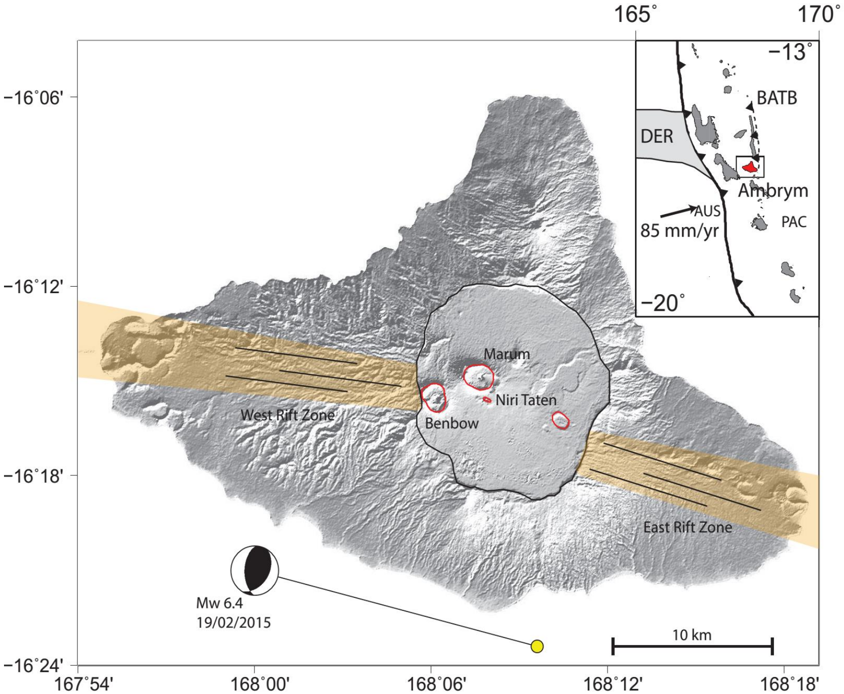
21st February 2015 Eruption



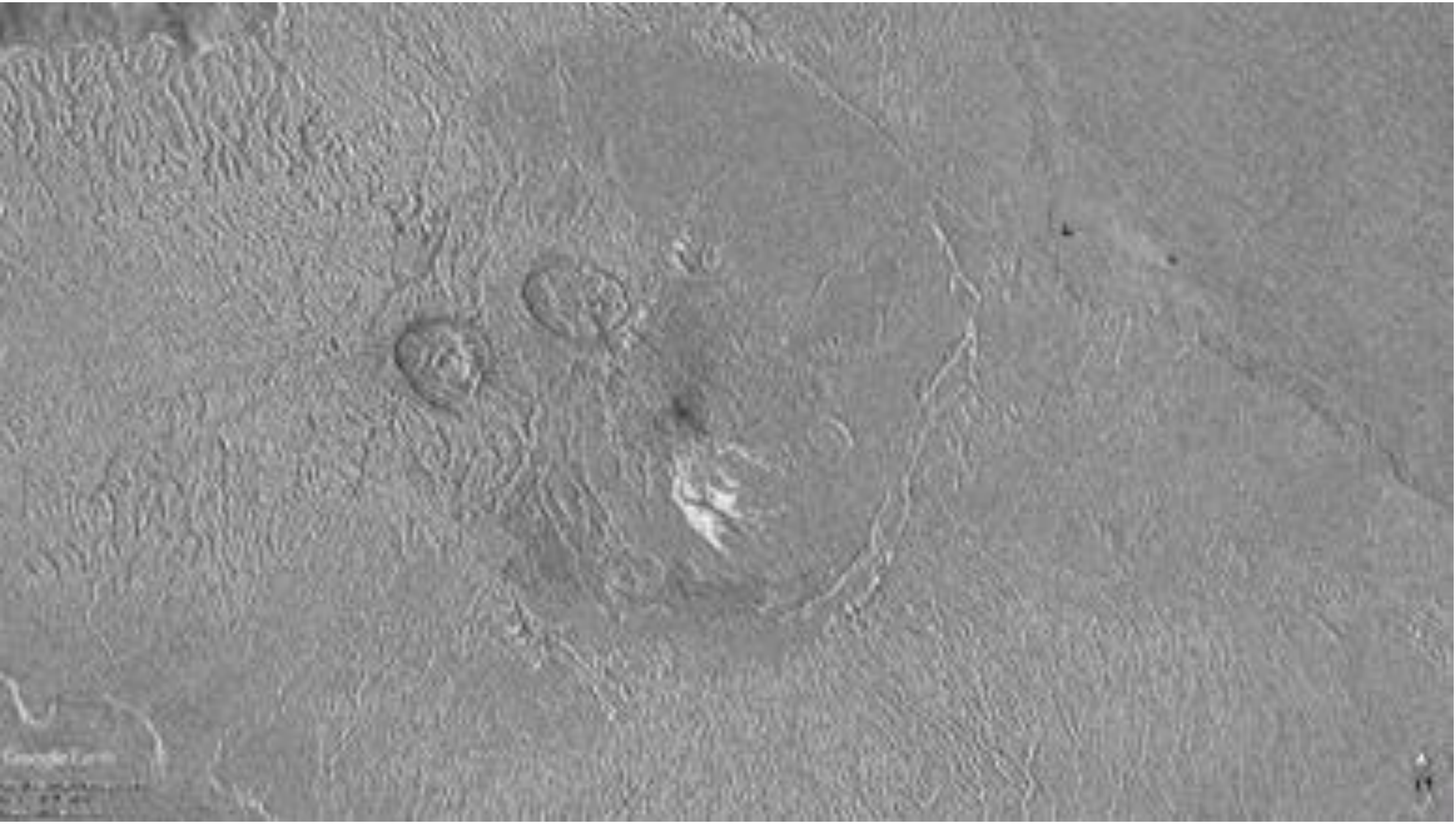
A new eruption was reported at Ambrym volcano, Vanuatu on 21st February 2015 from a new vent in the caldera.

It was the first new lava flow since 1989.

The eruption was preceded by a magnitude 6.4 earthquake 6 km south of Ambrym Island ~30 hours before.

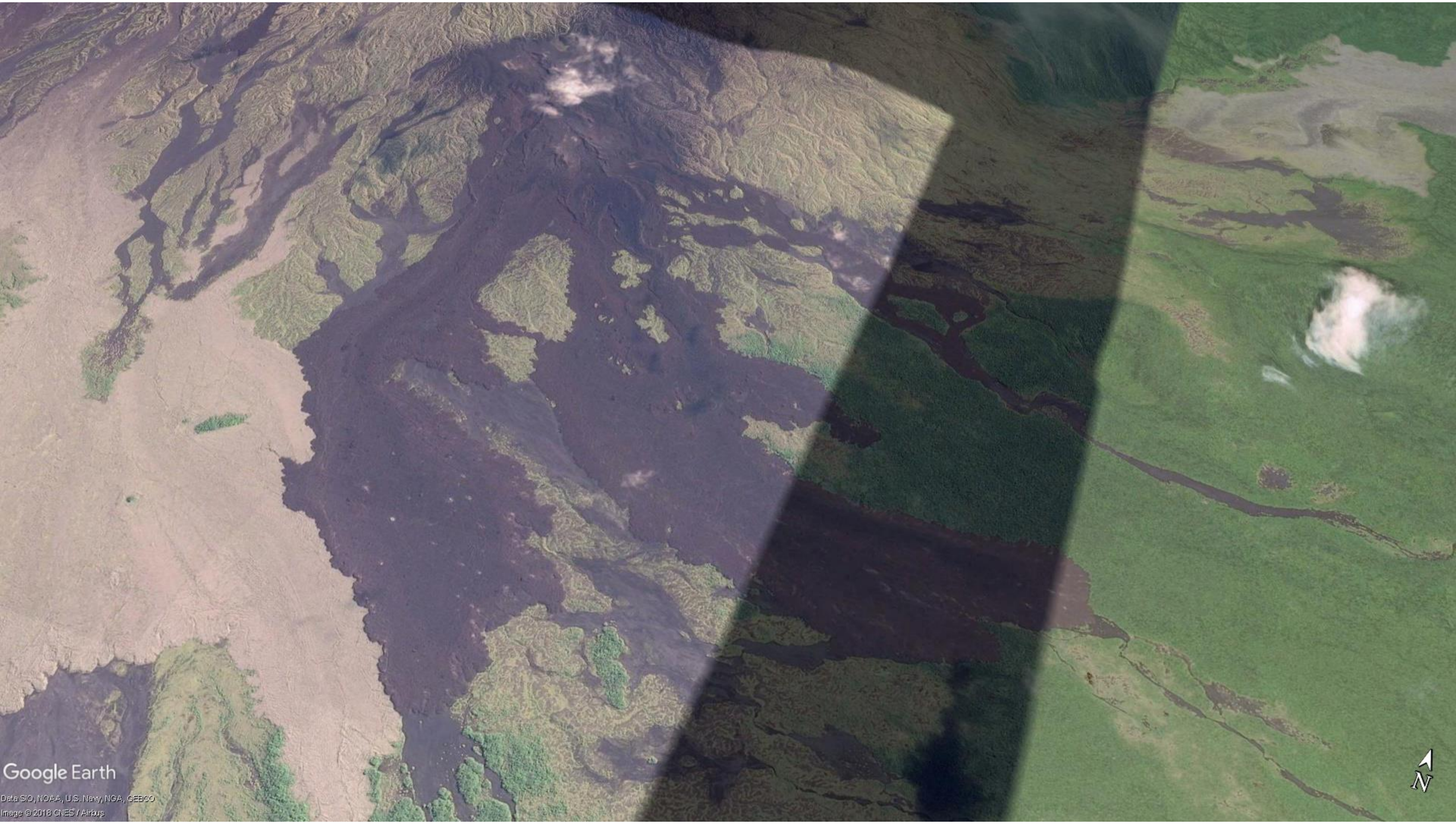


21st February 2015 Eruption

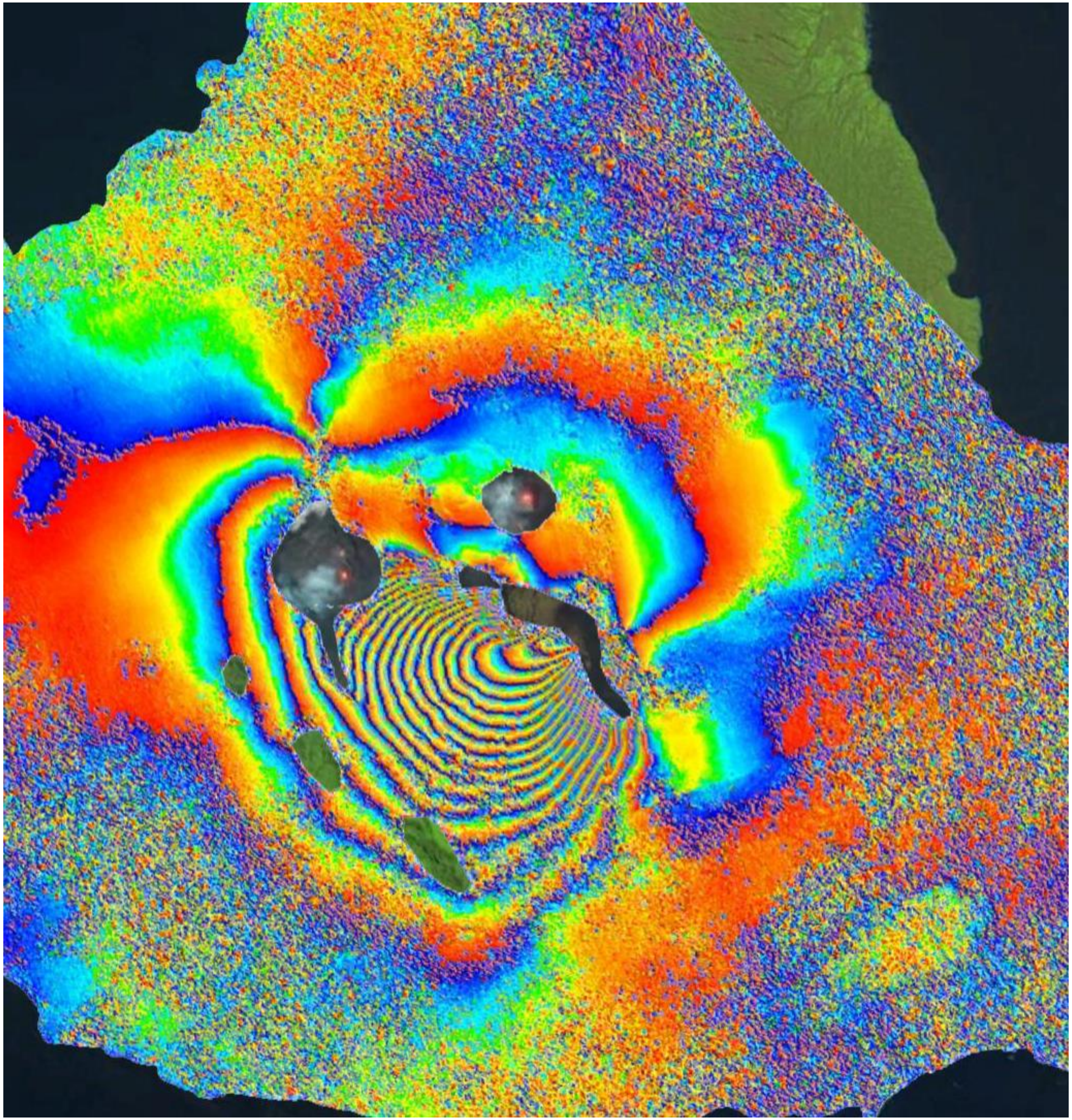


Difference in amplitude images

21st February 2015 Eruption

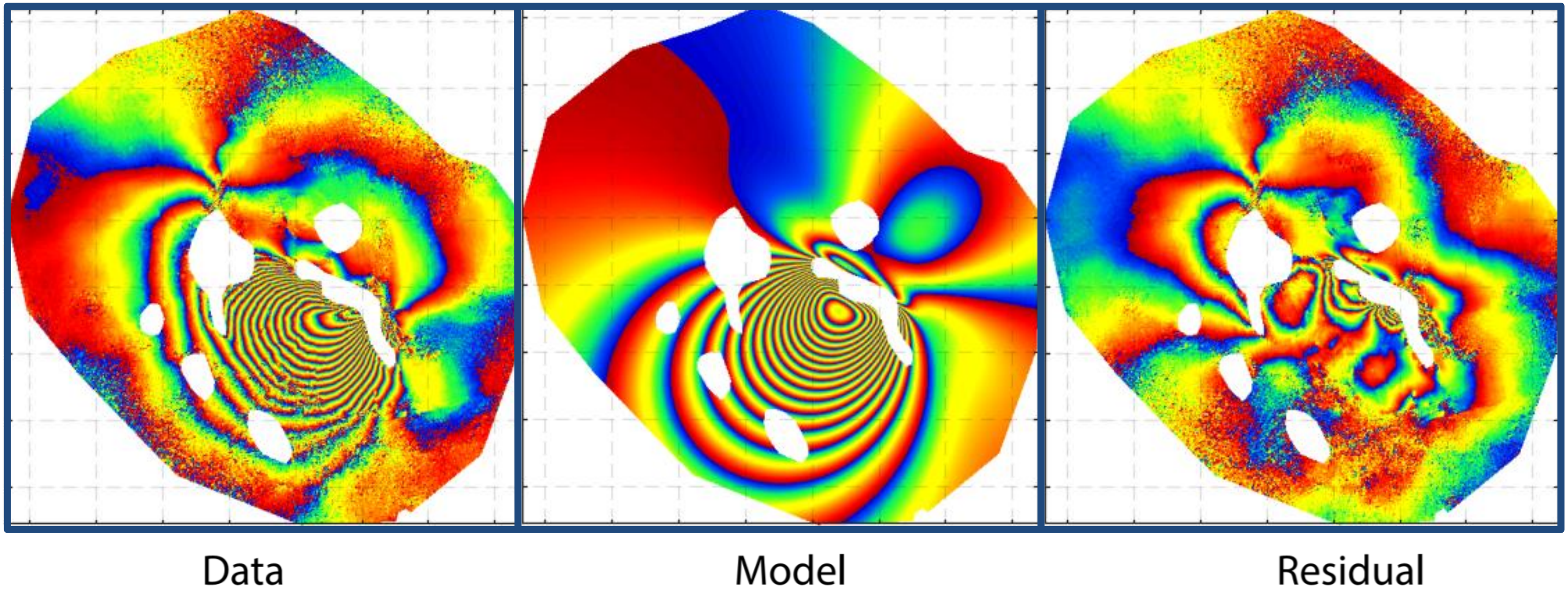


Assuming an average thickness of 1 m, lava flow was ~0.0013 km^3

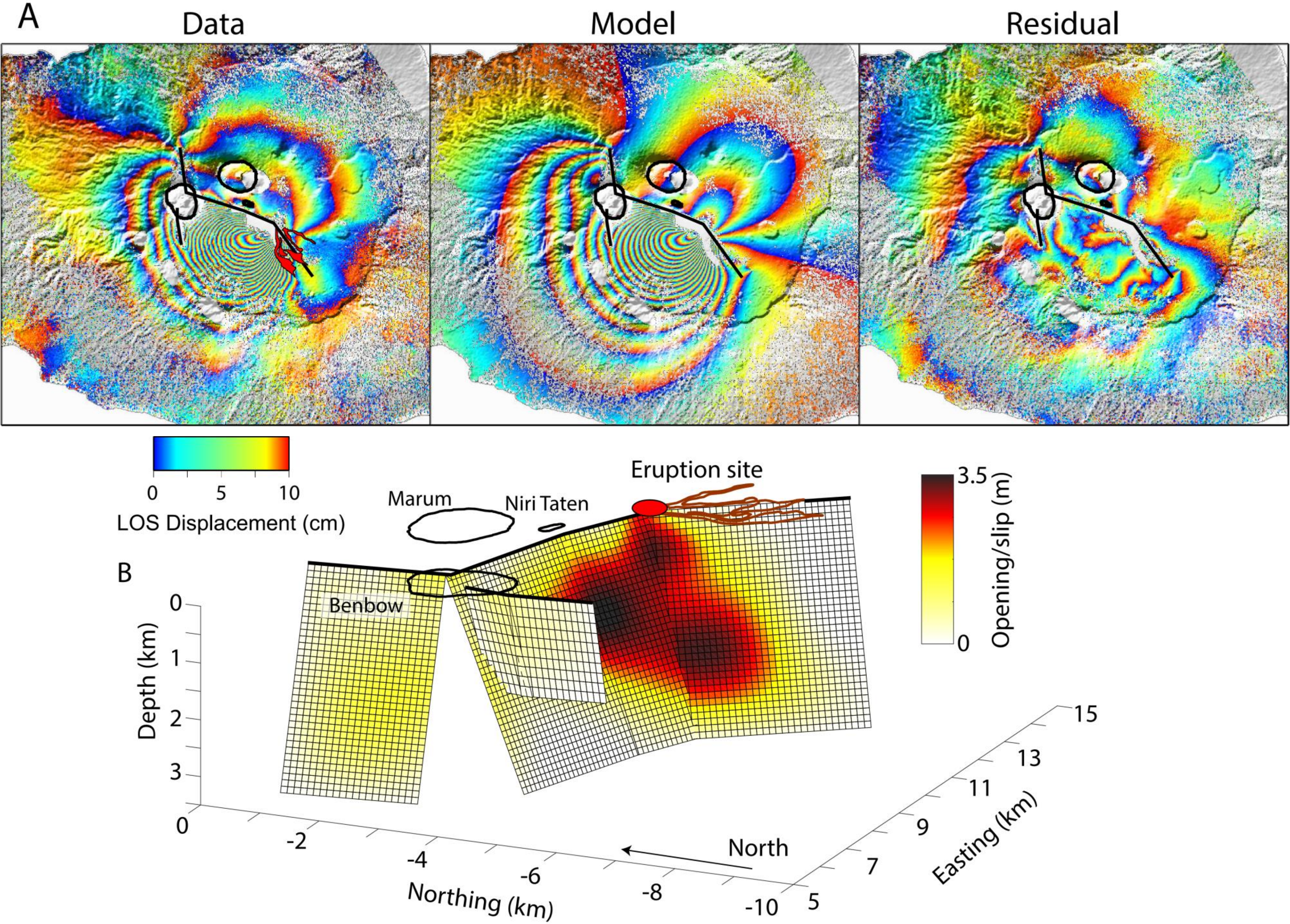


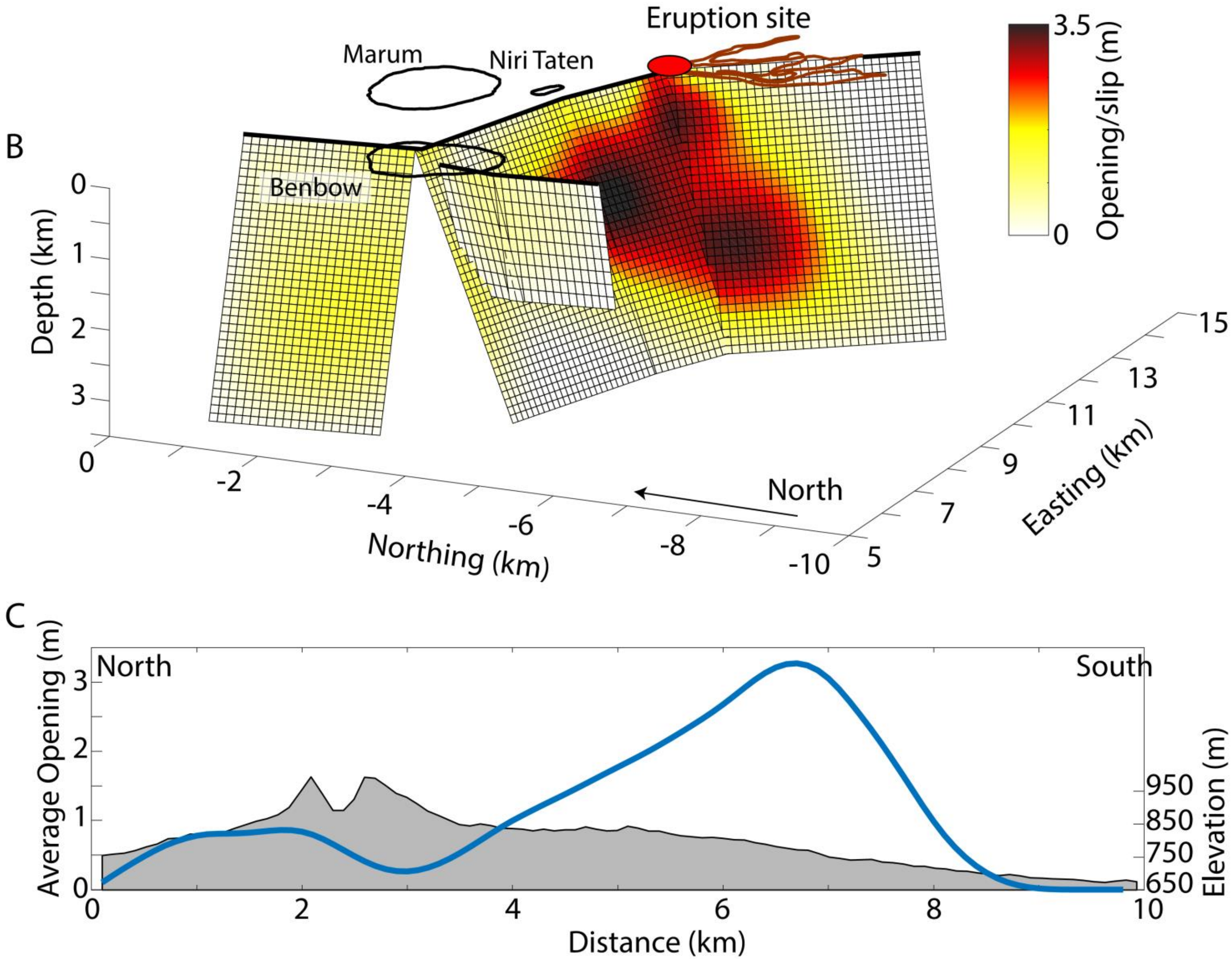
21/01/15
– 23/03/15

21st February 2015 Eruption

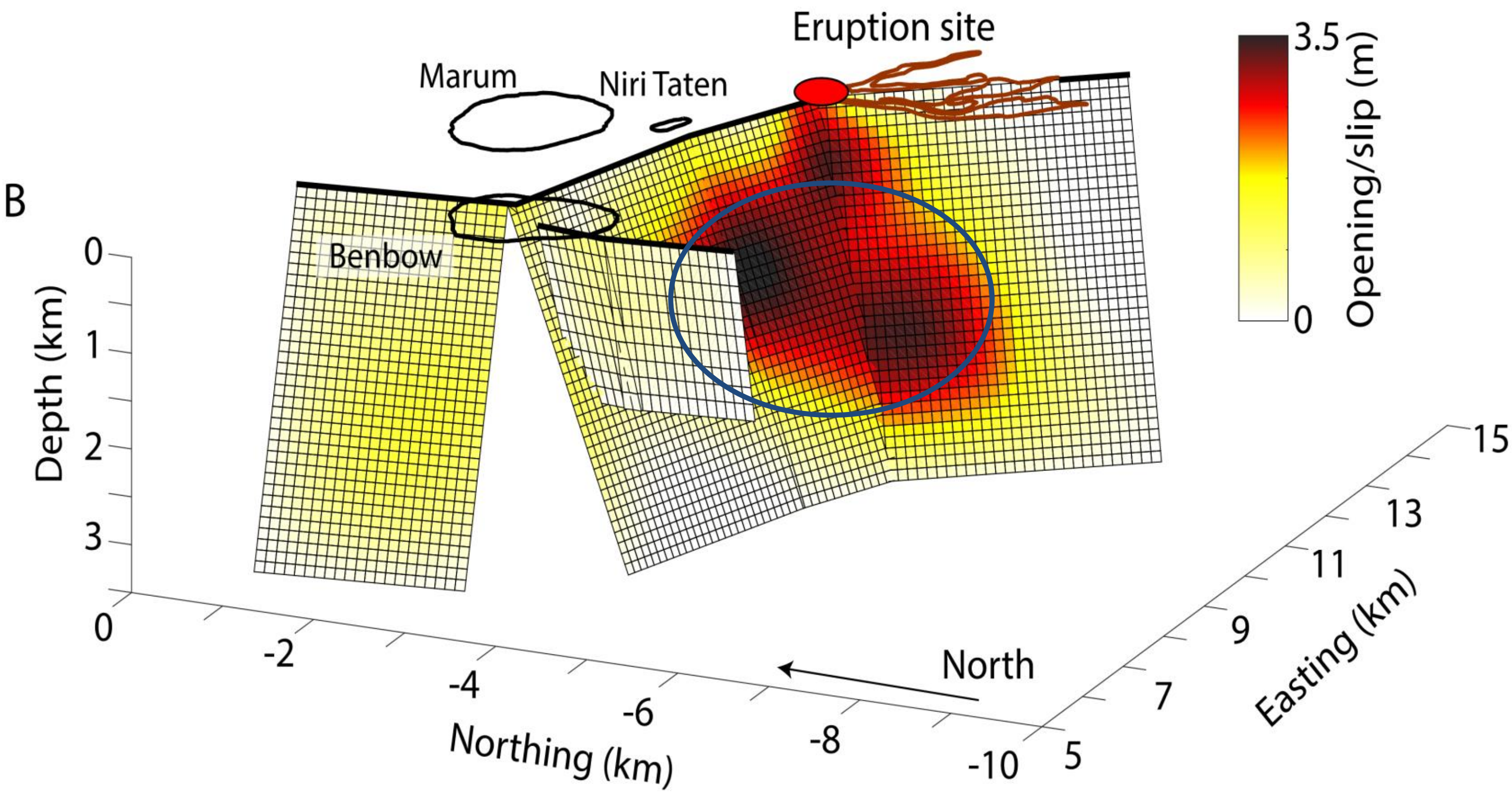


- Use GBIS (Geodetic Bayesian Inversion Software) to invert for best fitting uniform dyke
- Model suggests a 4-m-wide, 5-km-long dyke dipping at ~65°
- Using this geometry we discretize the dyke and solve for the best fitting distributed opening.


A
Data
Model
Residual
0
5
10
LOS Displacement (cm)
B
Eruption site
Marum
Niri Taten
Benbow
3.5
0
Opening/slip (m)
Depth (km)
0
1
2
3
0
-2
-4
-6
-8
-10
Northing (km)
North
5
7
9
11
13
15
Easting (km)



Length ~ 4 km, maximum opening ~3.5 m, volume 0.047 km^3



Assuming a half-width and length of 1.75 and 2000 m respectively and a Young's modulus of 20 GPa the overpressure in the dyke would be ~9 MPa

$$b = \frac{2P_0(1-\nu^2)L}{E}$$

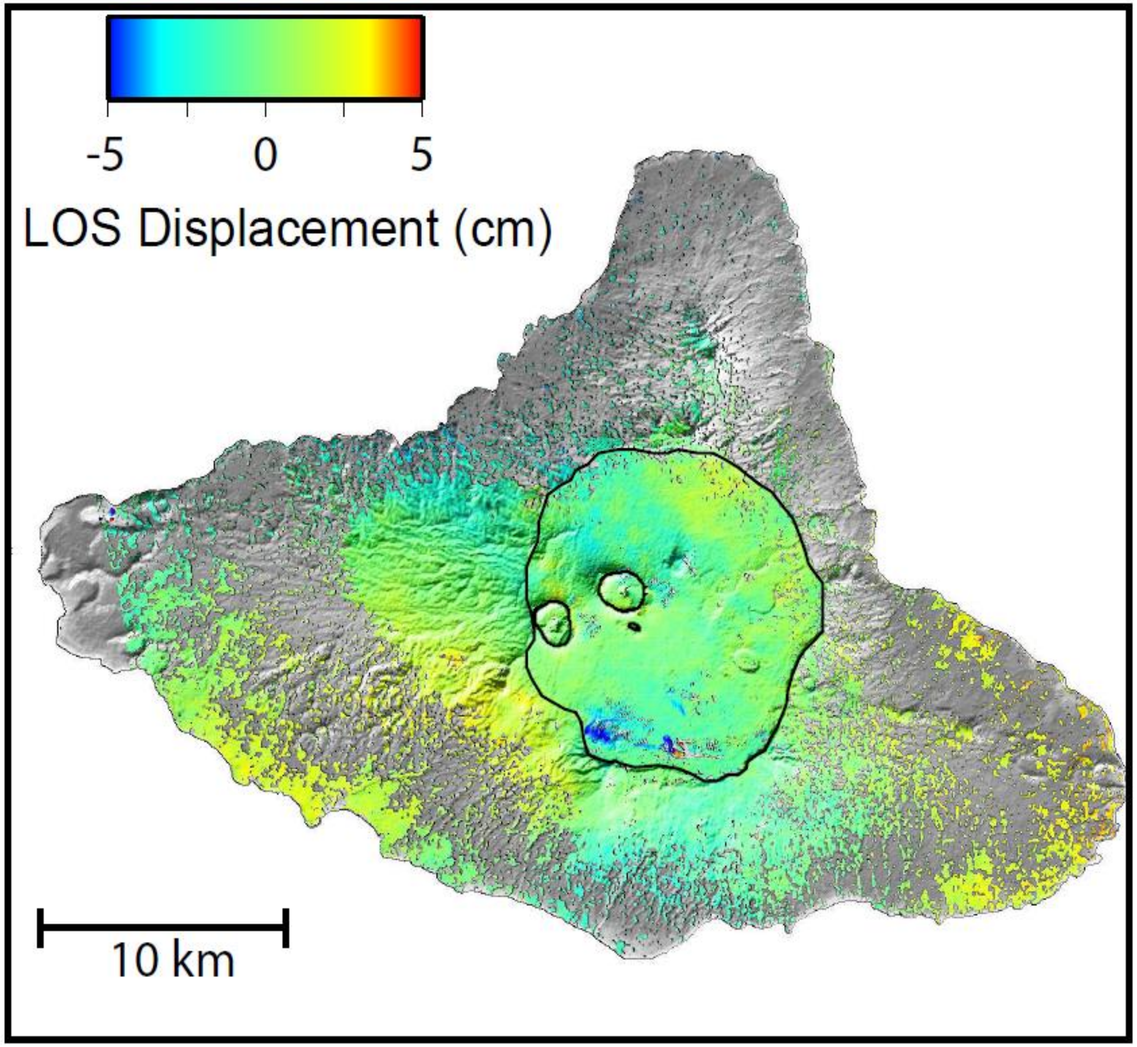
Where was the source?

Prior to the eruption there was no evidence of uplift across the caldera floor.

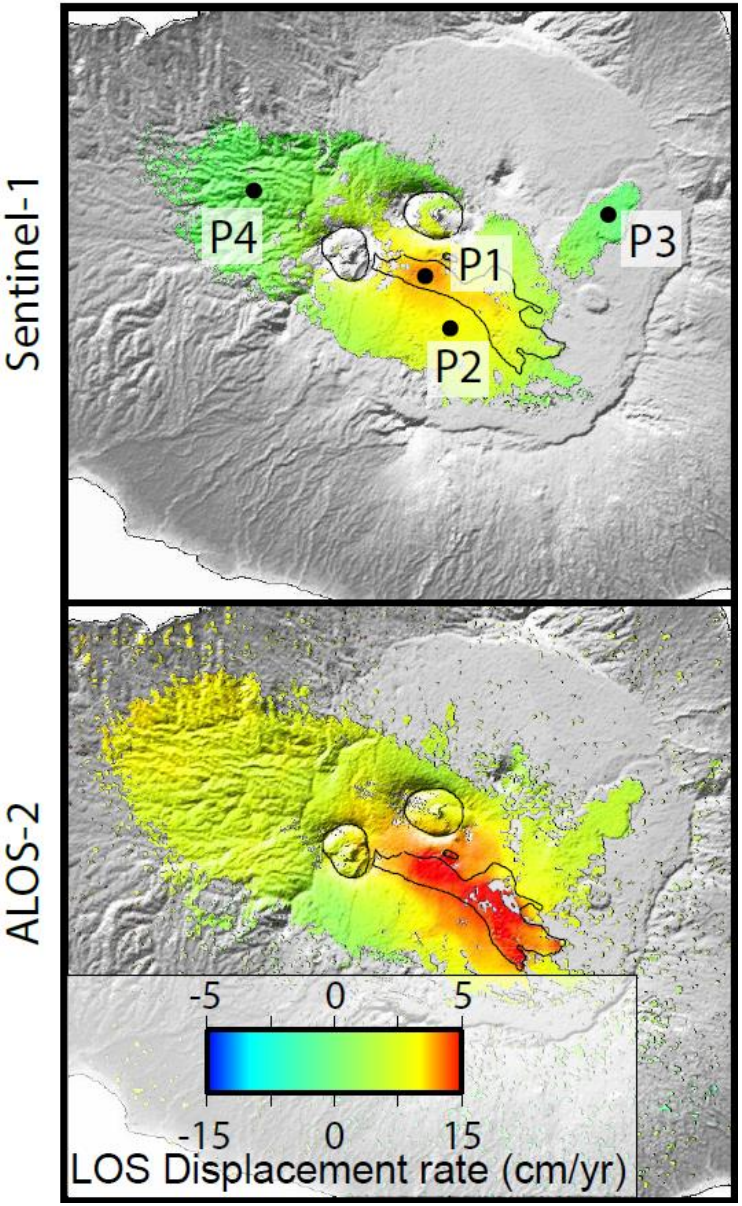
No real indication of withdrawal from beneath either of the cones.

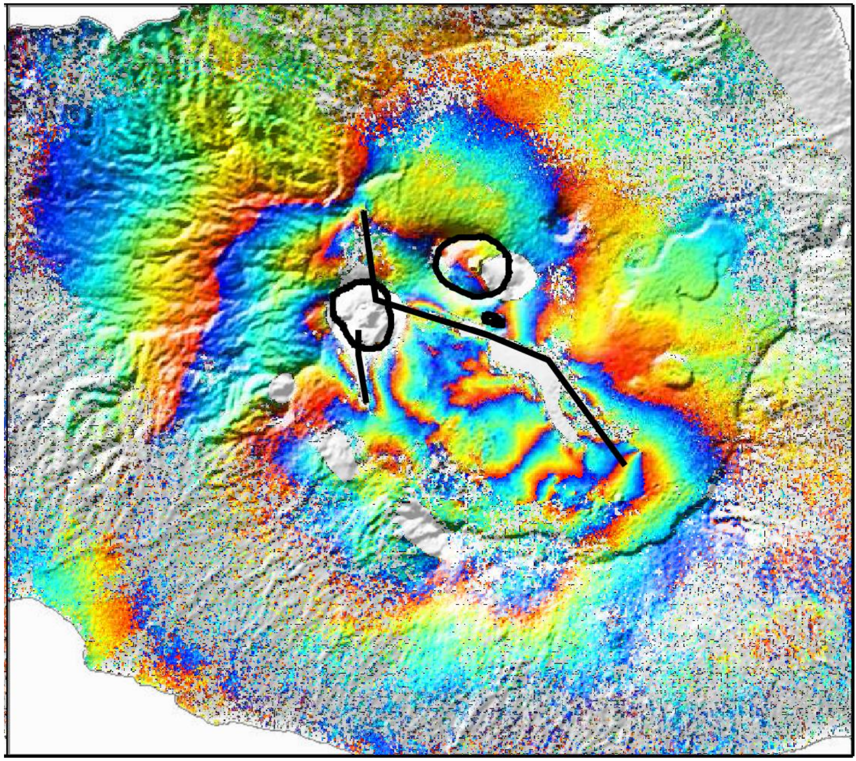
No reported drainage of lava lakes

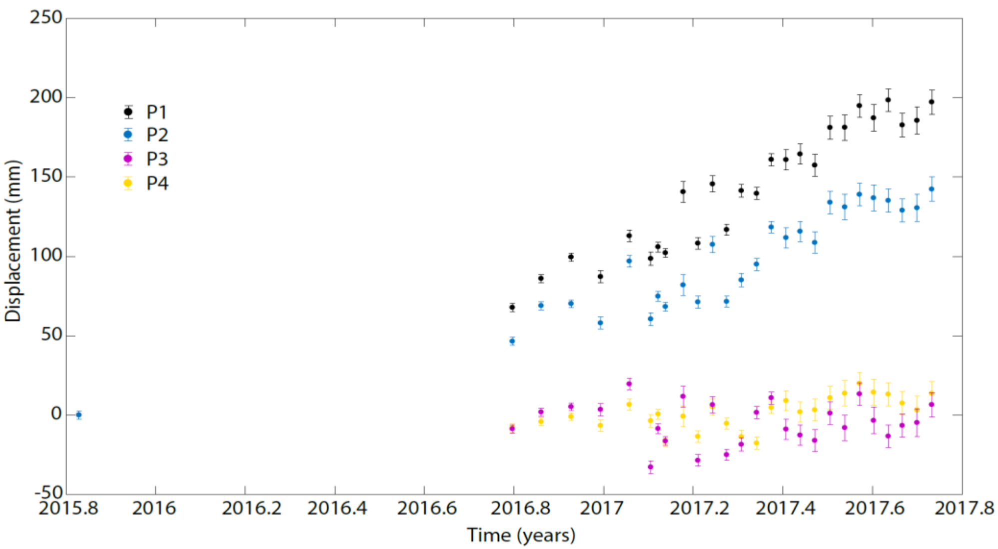
BUT…. Post eruption data shows broad subsidence signal which continues for ~2 years after the eruption



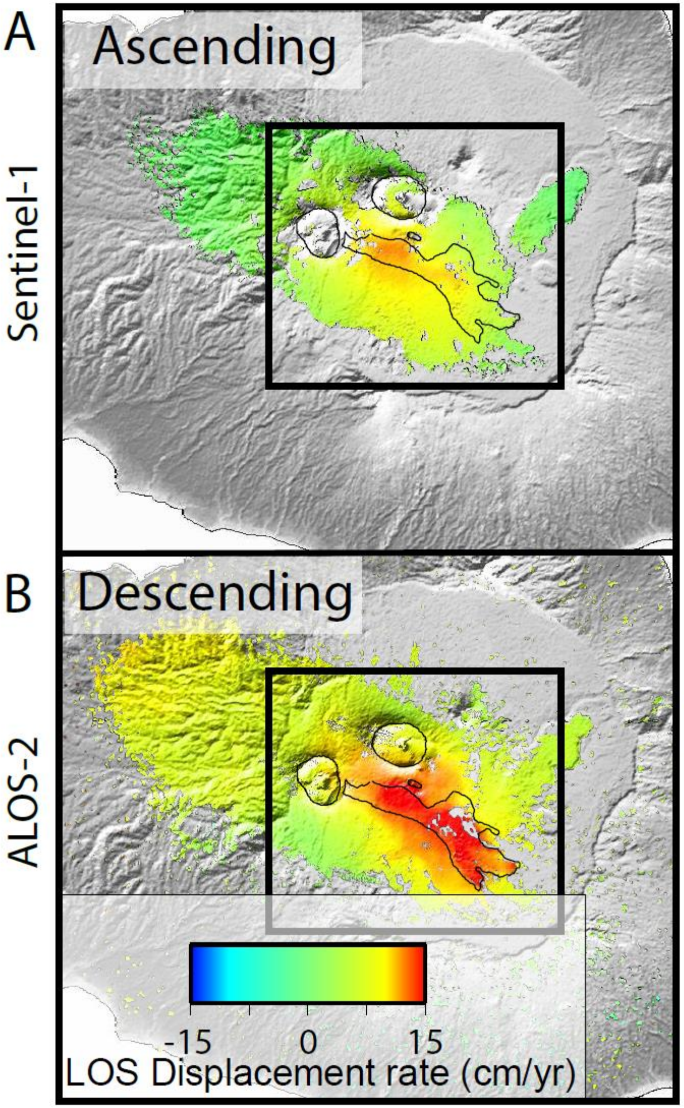
Where was the source?



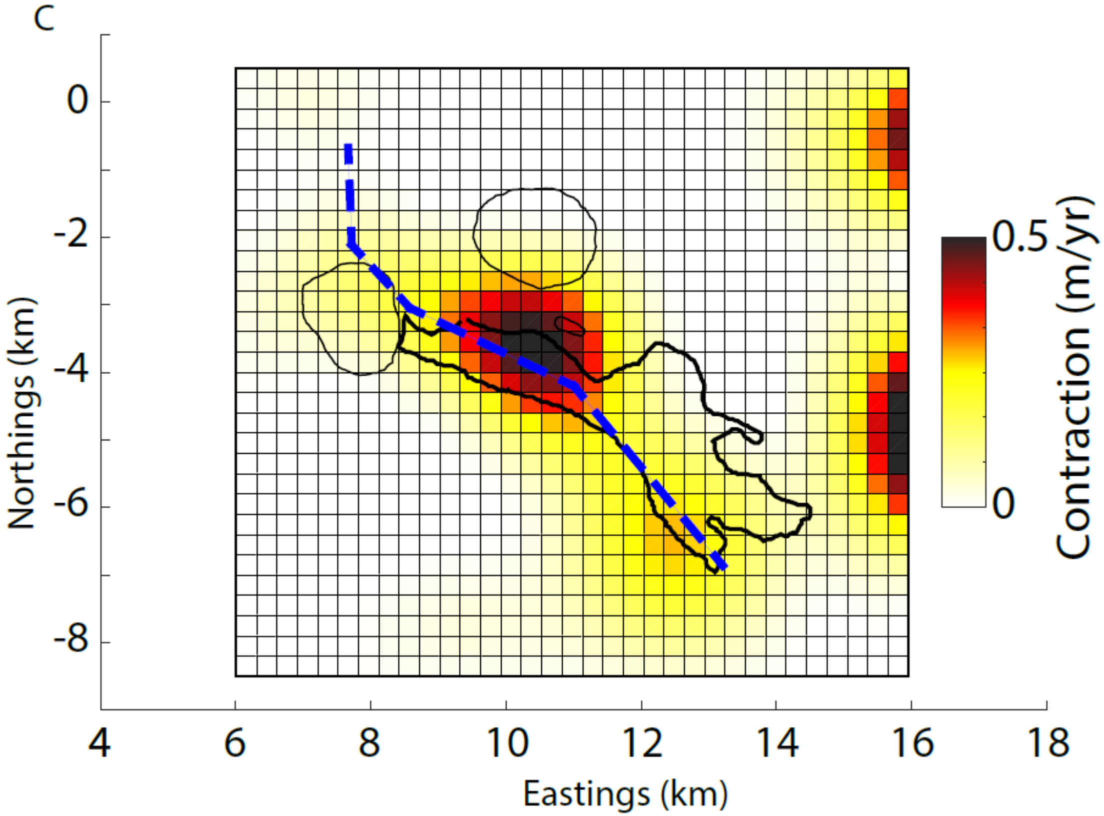




Where was the source?



Following the same modelling procedure we estimate a contracting source at ~3.5 km depth centred south of Niri Taten

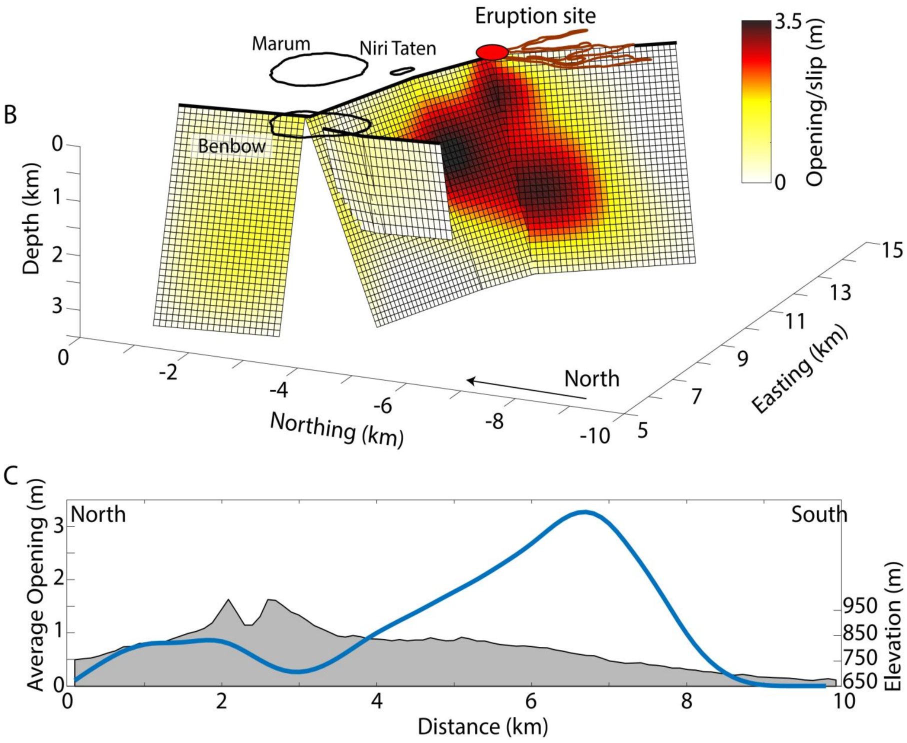


Was the intrusion triggered by the ~Mw 6.4 earthquake?

Growing number of observations indicating a short term correlation between earthquakes and eruptions.

Number of mechanisms have been suggested but perturbations to the stress field and subsequent growth of bubbles is a common explanation.

Based on the dyke model, the overpressure was ~9 Mpa. To achieve such an overpressure the excess pressure in the magma chamber is given by:

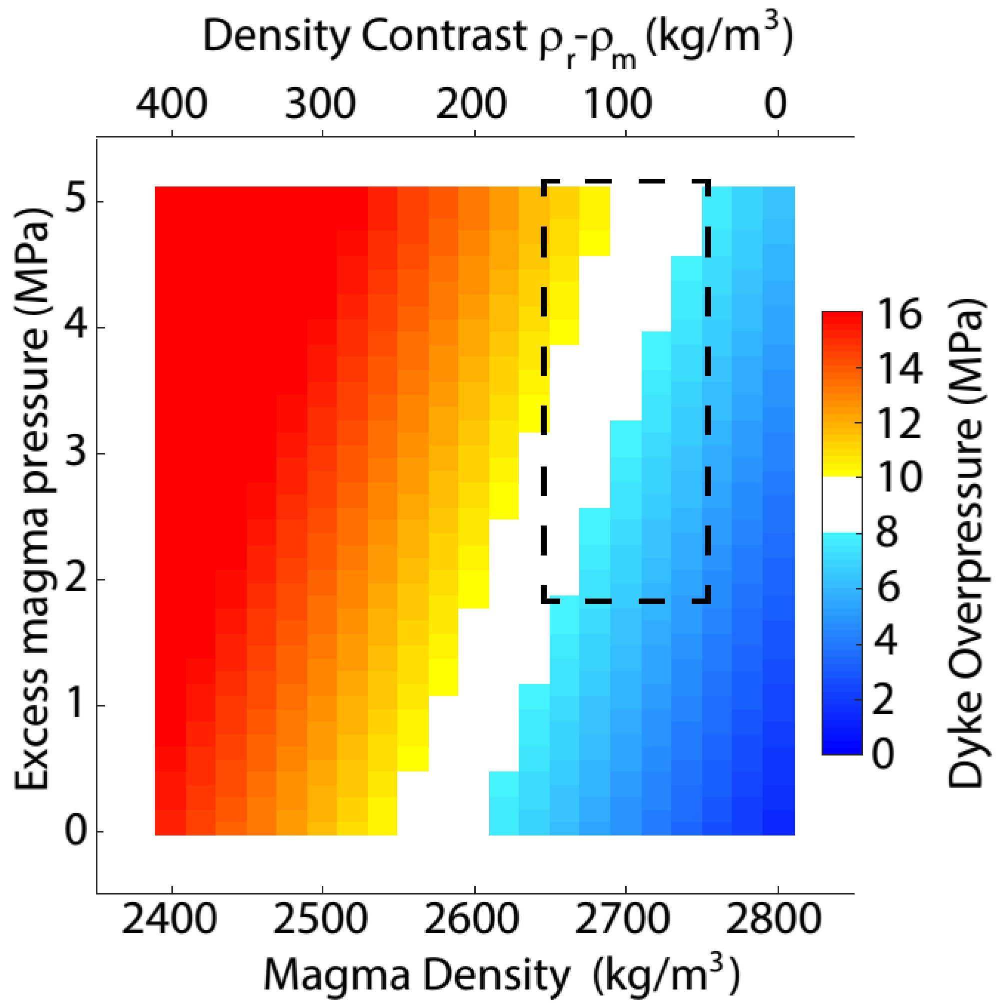


$$P_e = P_0 - (\rho_r - \rho_m)gh - \sigma_d$$

Was the intrusion triggered by the ~Mw 6.4 earthquake?

For a reasonable range of magma densities the excess pressure in the underlying chamber would need to be in excess of 2 MPa.

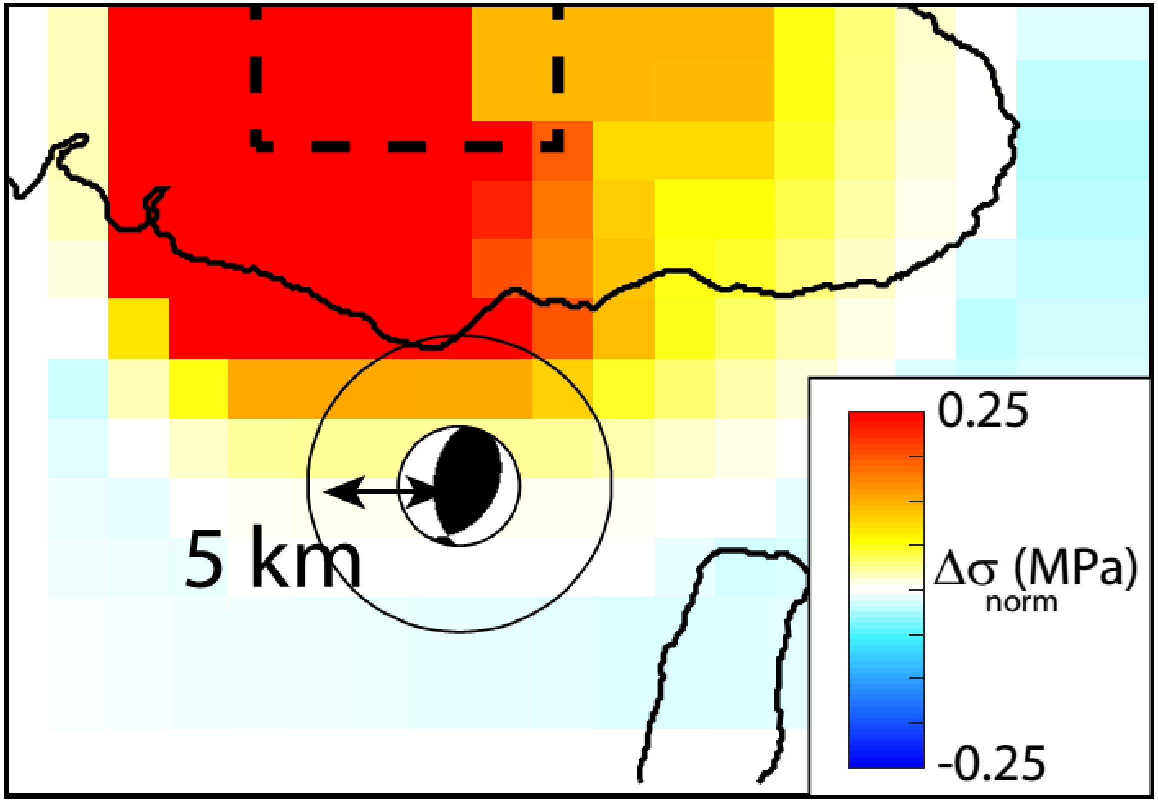
Taking the MT solution for the earthquake we can guesstimate the change in normal stress for our inferred horizontal source.



Was the intrusion triggered by the ~Mw 6.4 earthquake?

To account for location uncertainty, we systematically move the epicentre and calculate the stress change at each location

Maximum $\Delta\sigma_{norm}$



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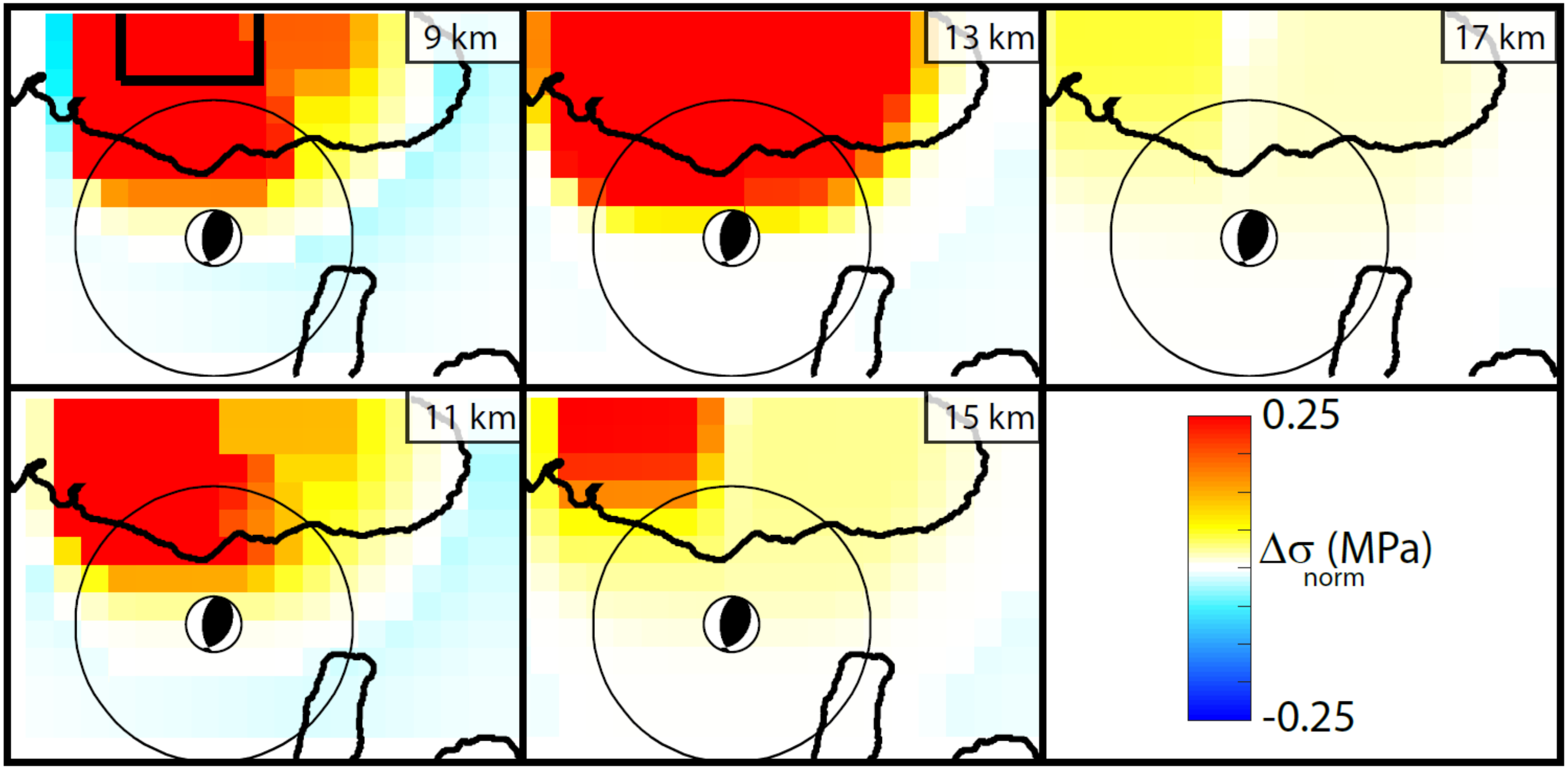
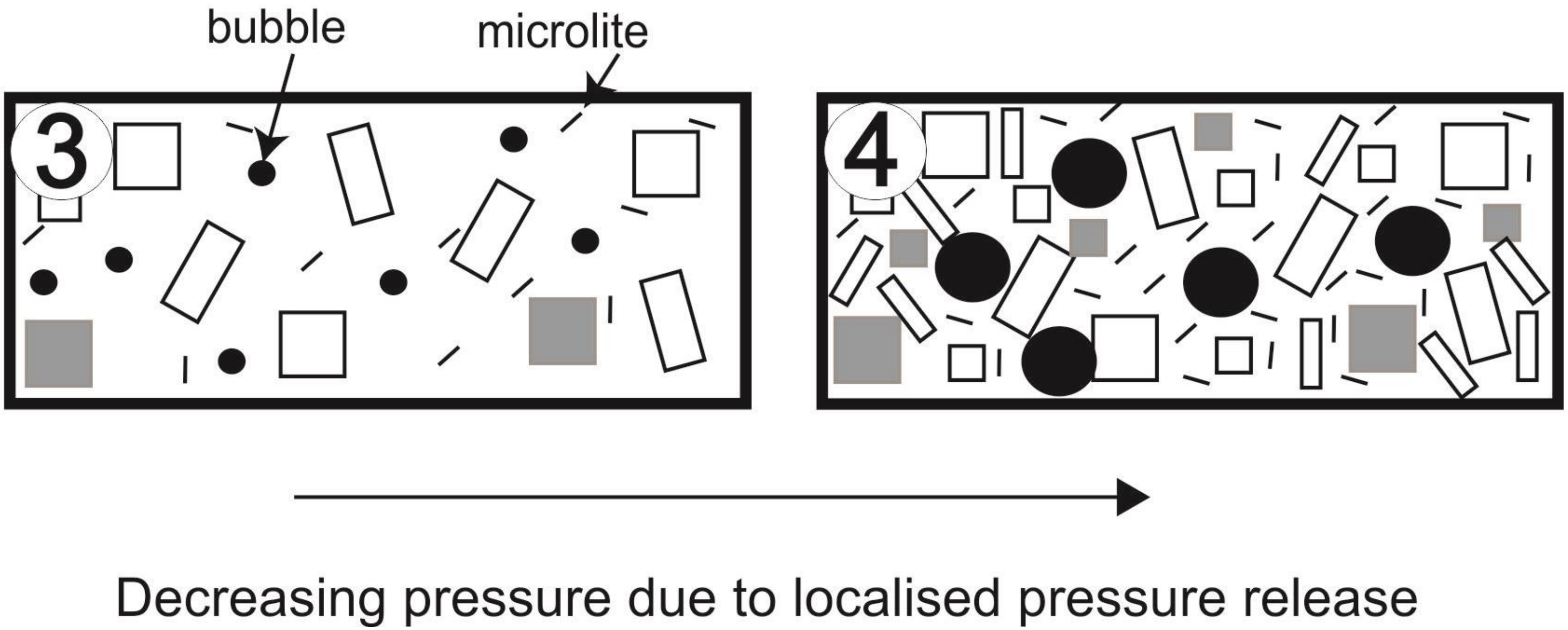


Considering a horizontal and vertical location error a maximum stress change of ~0.5-1.5 MPa

Was the intrusion triggered by the ~Mw 6.4 earthquake?

Using decompression models for Ambrym type basalt we examine the effect of a stress drop on bubble growth.

By promoting bubble growth, we can cause an overpressurisation following an initial pressure drop

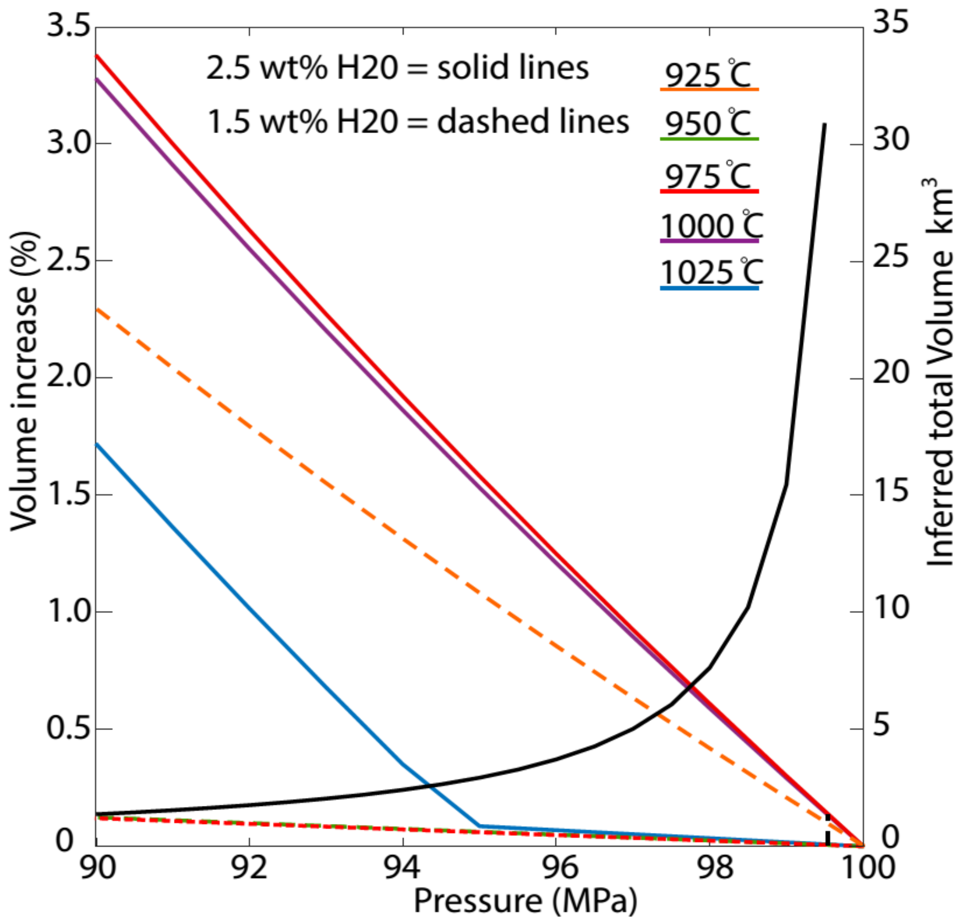


Was the intrusion triggered by the ~Mw 6.4 earthquake?

For higher temperature magmas, (≥ 1025°C) with 2.5 wt.% water, gas exsolution does not initiate until the pressure has dropped by 5 MPa

For the same magma with relatively low water contents, the initial pressure drop required for bubble growth is even larger.

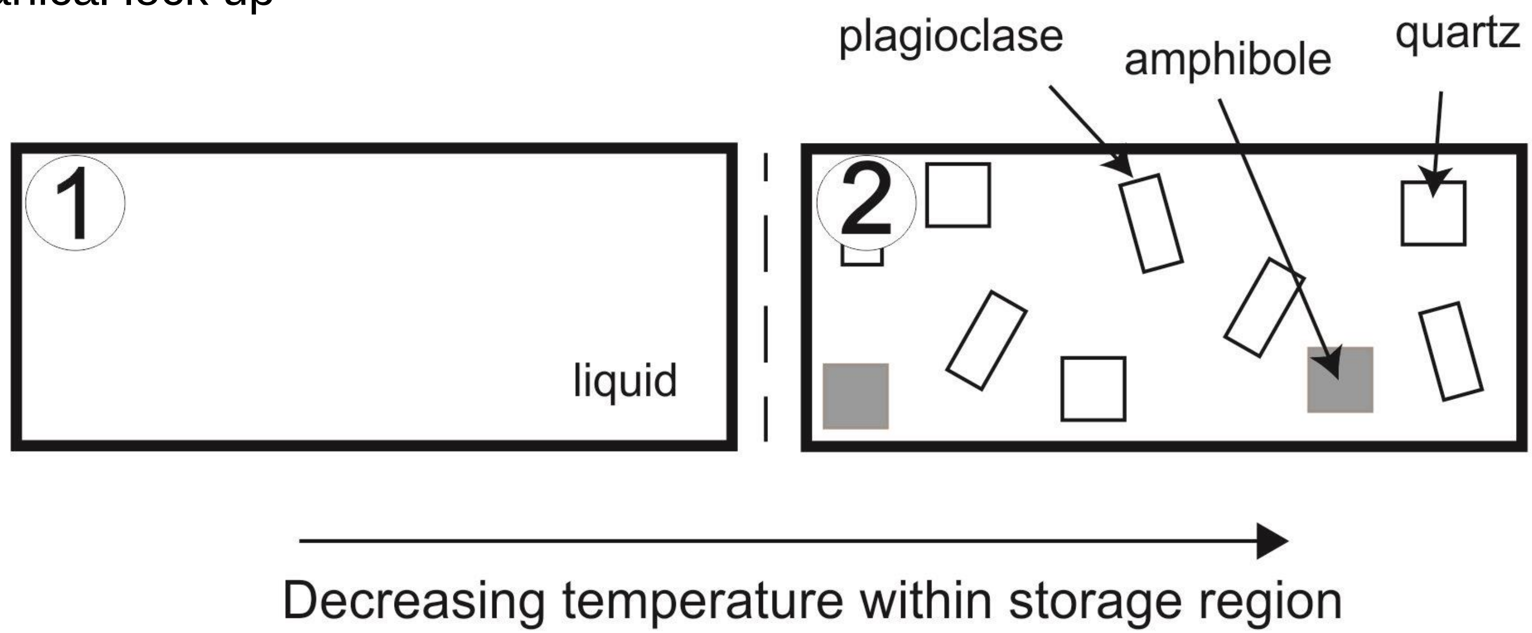
However, if the magma is cooler and H_2O saturated, small pressure drops (less than 1 MPa) are sufficient to promote bubble growth causing an increase in the magma volume and pressurization of the chamber.



Was the intrusion triggered by the ~Mw 6.4 earthquake?

However, as a magma cools we get more and more crystal growth.

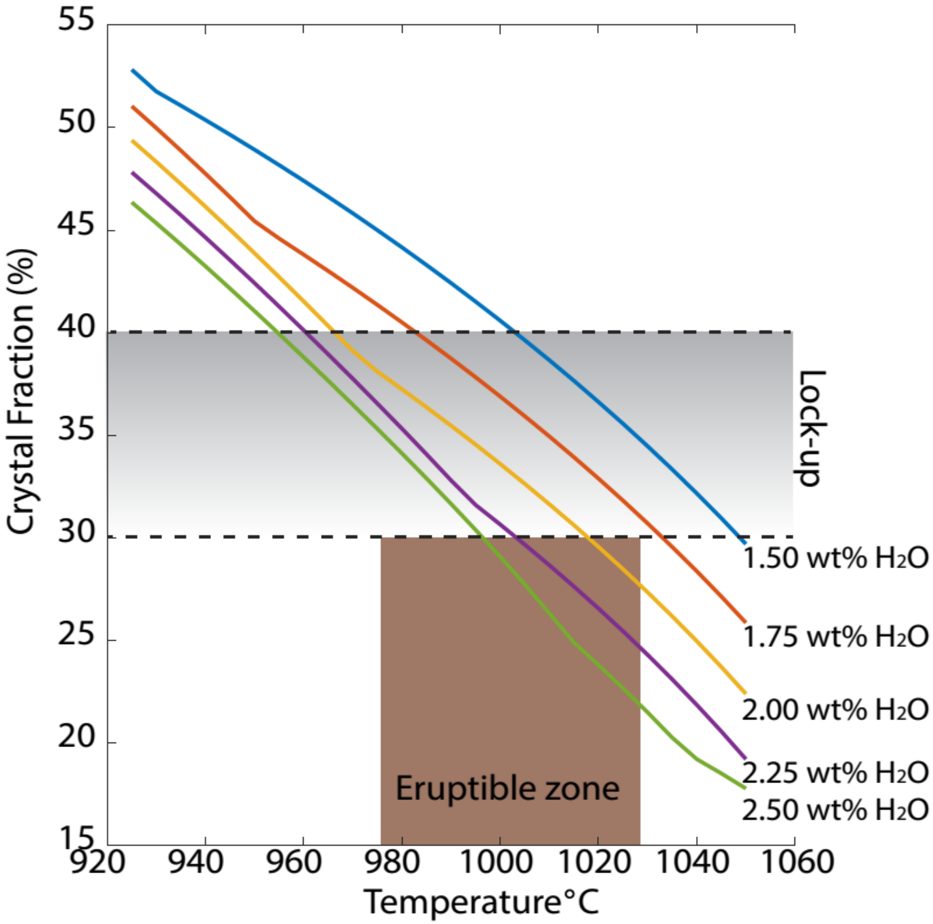
Experiments show that the viscosity of magma containing more than ~30-40% crystals will rise to a point of mechanical lock up



Was the intrusion triggered by the ~Mw 6.4 earthquake?

For magmas with 2-2.5 wt.% H2O, this places a lower bound temperature needed for mobility of around 970°C while for those with closer to 1.5 wt.% H2O the temperature is closer to 1030°C.

However, to get bubbles to grow in a magma at this temperature would require a ~40 MPa drop in pressure



Conclusions

- 2015 eruption at Ambrym was the result of a 3.5 m-wide dyke intrusion down the southern flanks
- Lack of co-eruptive subsidence at shallow systems suggests that the intrusion was sourced from depth
- Decompression models suggest that there is an optimum temperature window where small stress drops can generate large bubble growth to pressurise the magma while it remains eruptible
- These results imply that freshly intruded basalts intruded into shallow systems are too hot to generate significant bubble growth from small stress drops.